CHAPTER 5

RESULTS AND DISCUSSION

This chapter deals with the various results obtained in the experiments and discusses their relevance. The results include tool wear behavior, the surface roughness obtained, and the effectiveness of the AE monitoring.

5.1 TOOL WEAR STUDY

The value of the tool flank wear measured at various time instants of machining for all the three cutting speeds is given in Figure 5.1. The overall trend of the tool wear curves is similar to that observed in Figure 3.3, and the different wear zones are again not distinct. This is due to the edge honing provided in the cutting tool, which eliminates the run-in phase of the tool wear. The small feed and depth of cut, and the very high hardness of the work material, ensured a steady wear of the cutting tool. However, the wear become very rapid after the flank wear crossed the limiting value.

The tool life calculated for the tool wear criteria (Mohamed Athame yallese 2009) of $V_B = 0.3$ mm are 48 min, 24.5 min and 18.5 min for the cutting speeds 70 m/min, 100 m/min and 130 m/min respectively.
Figure 5.1 Tool Flank Wear Vs Machining Time for CBN tools (Commercial Grade MB 8025)

The photographs of the flank face and rake face of the cutting tools after the completion of wear testing are shown in Figures 5.2 to 5.7. The flank face images show very distinct wear scars. The images also show the abrasive wear that had taken place due to the rubbing between the hardened workpiece material and the tool.

Figure 5.3 shows the rake face of the cutting tool after 48 minutes of cutting at 70 m/min. One can see a very distinct crater formation, close to the cutting edge. The formation of crater very close to the cutting edge is due to the very small uncut chip thickness used in the metal cutting. In hard turning, the feed rate used is usually very small and this results in a crater formation very close to the cutting edge. This poses the danger of the crater wall opening up on the flank side, leading to the catastrophic fracture of the cutting edge making the tool unsuitable for further machining. Such opening up of the flank wall of the crater can be observed in Figures 5.5 and 5.7.
Figure 5.2  Flank Face of the Cutting Tool after 48 minutes of Machining (Cutting Speed 70m/min)

Figure 5.3  Rake Face of the Cutting Tool after 48 Minutes of Machining (Cutting Speed 70m/min)
Figure 5.4  Flank Face of the Cutting Tool after 24.5 Minutes of Machining (Cutting Speed 100m/min)

Figure 5.5  Rake Face of the Cutting Tool after 24.5 Minutes of Machining (Cutting Speed 100m/min)
Figure 5.6  Flank Face of the Cutting Tool after 18.5 Minutes of Machining (Cutting Speed 130m/min)

Figure 5.7  Rake Face of the Cutting Tool after 18.5 Minutes of Machining (Cutting Speed 130m/min)
5.2 SURFACE ROUGHNESS AND TOOL WEAR

Table 5.1 Initial surface roughness of the Hardened Steel specimen before Machining

<table>
<thead>
<tr>
<th>Specimen number</th>
<th>Usage of specimen for the cutting speeds</th>
<th>Surface roughness value (Ra) [µm] before machining</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>70 m/min</td>
<td>0.284</td>
</tr>
<tr>
<td>2</td>
<td>100 m/min</td>
<td>0.476</td>
</tr>
<tr>
<td>3</td>
<td>130 m/min</td>
<td>0.373</td>
</tr>
</tbody>
</table>

The observed values of Ra before machining is shown in Table 5.1. Figure 5.8, 5.9 and 5.10 show the plot of the surface roughness measured in terms of Ra and Rz as a function of the tool flank wear, for cutting speeds of 70 m/min, 100 m/min and 130 m/min respectively. Figure 5.8, plotted for a cutting speed of 70 m/min, shows the maximum Ra value of the surface roughness to be about 0.63 µm, when the flank wear was less than 0.3mm. Similarly for a cutting speed of 100 m/min and 130 m/min the maximum Ra values when the flank wear land was within limits are around 1 µm or less. These observations reaffirm the use of hard turning as a finishing operation.
Figure 5.8 Effect of Flank Wear on Surface Roughness at $V_c = 70$ m/min

Figure 5.9 Effect of Flank Wear on Surface Roughness at $V_c = 100$ m/min
From the figures 5.8 to 5.10, it can also be observed that, at various stages of tool wear, the surface roughness Ra and Rz values were found to increase as the cutting speed was increased from 70 to 100 m/min and were then again found to decrease to a much lower value at 130 m/min. The optimal cutting speed from the surface roughness point of view appears to be 130 m/min. Anyhow further experiments at higher cutting speeds are to be conducted for ascertaining this.

5.3 TOOL WEAR MONITORING

5.3.1 Skew in Hard Turing

The $AE_{RMS}$ signals captured during the experiments were stored in the computer as a set of 2,000 data points. These data represent the RMS value of the AE signal computed with an integration time constant of 0.12 ms. Kannatey-Asibu and Dormfeld (1982) had assumed these $AE_{RMS}$ values to
follow a $\beta$-distribution, and observed the skew and kurtosis of this
distribution to be sensitive to tool wear in conventional turning.

The skew of $AE_{\text{RMS}}$ signals can be computed using the mean ($\mu$) and
variance ($\sigma$) of the distribution, assuming the signal to follow a $\beta$-distribution
using the expressions given in equations 2.5. The skew values of the $AE_{\text{RMS}}$
signal were computed, for various wear states of the tool for all the cutting
speeds. The plots showing the skew of $AE_{\text{RMS}}$ as a function of tool wear, are
shown in figures 5.11 to 5.13.

![Figure 5.11 Skew of $AE_{\text{RMS}}$ Signal Vs Flank Wear $V_c = 70$ m/min](image-url)
The skew of any distribution function measures the symmetry about its mean level. A positive skew means the right tail of the distribution curve is longer and the mass of the distribution is concentrated on left. A negative
skew means, the left tail is longer and the mass of distribution is concentrated on the right (Figure 5.14).

Figures 5.11 to 5.13 show the skew of $AE_{RMS}$ decreasing steadily as the flank wear land increases. In the physical realm, this means very strong, high amplitude AE bursts occurring, as the cutting tool wear increases. This results in some high amplitude $AE_{RMS}$ values thereby shifting the mass of the distribution more to the right. This is quite logical because as the tool wear land increases there is likely to be greater rubbing between the tool and the workpiece, leading to the generation of a few high amplitude AE signal.

In Figures 5.12 and 5.13 the skew becomes negative, after the flank wear crosses the limiting value of 0.3 mm. This could be due to the opening up of the crater along the flank wall. As the crater wall opens on the flank side, the proper cutting edge is lost and this could lead to a lot of rubbing and micro fractures taking place, contributing to the negative skew.

### 5.3.2 Kurtosis in Hard Turning

The kurtosis values of the $AE_{RMS}$ distribution were computed using equation 2.6. The computed values of kurtosis based on $AE_{RMS}$ were plotted
as a function of flank wear at various cutting speeds (70, 100 and 130 m/min), and are represented in Figures 5.15 to 5.17. As the flank wear increases, the kurtosis values are found to increase. This increase became very sharp, when the flank wear is around 0.3 mm.

Figure 5.15 Kurtosis of AE_{RMS} Signal Vs Flank wear at \( v_C = 70 \) m/min

Figure 5.16 Kurtosis of AE_{RMS} Signal Vs Flank Wear at \( V_C = 100 \) m/min
As can be seen in Figure 5.18, kurtosis is a measure of the sharpness of the peak of the distribution. In any distribution, if we have high frequency entries occurring around the central value, then the distribution will have high kurtosis. In metal cutting, the generation of acoustic emission is from many sources. The high values of kurtosis, as the flank wear land reaches the
critical value, indicate the emission due to rubbing becoming more prominent. This trend can be observed in all plots in Figures 5.15 to 5.17.

5.3.3 \( \text{AE}_{\text{RMS}} \) Distribution and Tool Wear

To understand the changes taking place in \( \text{AE}_{\text{RMS}} \) distribution taking place as the tool wears, the distribution plots of \( \text{AE}_{\text{RMS}} \) amplitude were drawn. From the 2,000 data points pertaining to a particular cutting speed and tool wear status, the frequency of the occurrence of \( \text{AE}_{\text{RMS}} \) at different class intervals were computed in Table 5.2.

The distribution of \( \text{AE}_{\text{RMS}} \) values plotted as a histogram is shown in Figure 5.19.

For better visualisation the distribution is drawn as a continuous curve, taking the mid value of the intervals on the X-axis and the frequency of occurrence on the Y-axis. The \( \text{AE}_{\text{RMS}} \) distribution plot for a cutting speeds 70 m/min at different stages of flank wear is shown in Figure 5.20 and Figure 5.21.

The figures clearly show the mass distributions shifting to the right as the tool wears, which is responsible for the value of skew reducing. The figures also show the central value becoming sharper as the tool wears, which is responsible for the increase in the kurtosis.
Table 5.2  \( \text{AE}_{\text{RMS}} \) Frequency At Different Class Intervals  
\( (V_c = 130 \text{ m/min}, V_B = 0.03 \text{mm}) \)

<table>
<thead>
<tr>
<th>AE\text{RMS} amplitude Intervals (volts)</th>
<th>Mean AE\text{RMS} (Volts)</th>
<th>Frequency of occurrence</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 0.224</td>
<td>0.112</td>
<td>0</td>
</tr>
<tr>
<td>0.225 - 0.25</td>
<td>0.2375</td>
<td>0</td>
</tr>
<tr>
<td>0.255 - 0.275</td>
<td>0.265</td>
<td>0</td>
</tr>
<tr>
<td>0.276 - 0.3</td>
<td>0.288</td>
<td>152</td>
</tr>
<tr>
<td>0.305 - 0.325</td>
<td>0.315</td>
<td>481</td>
</tr>
<tr>
<td>0.326 - 0.35</td>
<td>0.388</td>
<td>574</td>
</tr>
<tr>
<td>0.355 - 0.375</td>
<td>0.365</td>
<td>560</td>
</tr>
<tr>
<td>0.376 - 0.4</td>
<td>0.388</td>
<td>227</td>
</tr>
</tbody>
</table>

Figure 5.19  \( \text{AE}_{\text{RMS}} \) Distribution  
\( (V_c = 130 \text{ m/min}, V_B = 0.03 \text{mm}) \)
Figure 5.20  Distribution Curve Showing Variation in Skew and Kurtosis at Various Flank Wear For $V_c = 70$ m/min

Skew = 0.15268, kurtosis = 0.02023

Skew = 0.140606, kurtosis = 0.02639

Skew = 0.010137, kurtosis = 0.031339

Figure 5.21  Distribution curve showing variation in skew and kurtosis at various flank wear for $V_c = 130$ m/min
5.4 SUMMARY OF DISCUSSIONS

This chapter attempted to monitor the tool wear in hard turning using the statistical parameters of AE_{RMS} distribution. The experiments had clearly demonstrated the possibility of using the skew and kurtosis of AE_{RMS} distribution for effectively monitoring the tool flank wear.